

## ***Interactive comment on “Reconciling single chamber Mg/Ca with whole test $\delta^{18}\text{O}$ in surface to deep dwelling planktonic foraminifera from the Mozambique Channel” by J. Steinhardt et al.***

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Referee3: Review of the manuscript "Reconciling single chamber Mg/Ca with whole test  $\delta^{18}\text{O}$  in surface to deep dwelling planktonic foraminifera from the Mozambique Channel" by J. Steinhardt, C. Cleroux, L. de Nooijer, G.-J. Brummer, R. Zahn, G. Ganssen, and G.-J. Reichart. This manuscript presents a large data set of single specimen stable isotopes and single chamber Mg/Ca on four species of planktonic foraminifera from a sediment trap in the Mozambique Channel which is affected by eddies. These lead to slightly different conditions in the water column affecting foram geochemistry. The authors argue that differences in the two sets, i.e. eddy and non-eddy

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conditions, show that combined stable isotopes and Mg/Ca can be used to reconstruct eddy conditions. Although the data set which is presented is large and very interesting, I'm not convinced that the data show that eddies can be reconstructed with this. For me, the data show how large the variability in single specimen/chamber geochemistry is (which feels more like the main theme of the paper) and that eddy occurrence with different conditions leads to similarly large variations. The range in values for both settings is very large and therewith seems to exclude that it would be possible in a downcore study to make the distinction. The manuscript is generally well-written, but contains many small mistakes giving the feeling that it has been written in a hurry. See below for more detailed comments, but one example is the method section on Mg/Ca. This seems to be copied one to one from a previous paper, the cited papers are missing from the references, and a whole series of elements are mentioned which never show up in the rest of the manuscript. In summary, I recommend that this study is potentially very interesting and fitting in Biogeosciences, but still needs a lot of work. As such I recommend to return the manuscript to the authors with major revisions.

General comments The authors argue that differences in the two sets, i.e. eddy and non-eddy conditions, show that combined stable isotopes and Mg/Ca can be used to reconstruct eddy conditions. Although the data set which is presented is large and very interesting, I'm not convinced that the data show that eddies can be reconstructed with this. For me, the data show how large the variability in single specimen/chamber geochemistry is (which feels more like the main theme of the paper) and that eddy occurrence with different conditions leads to similarly large variations. The range in values for both settings is very large and therewith seems to exclude that it would be possible in a downcore study to make the distinction. The manuscript is generally well-written, but contains many small mistakes giving the feeling that it has been written in a hurry. See below for more detailed comments, but one example is the method section on Mg/Ca. This seems to be copied one to one from a previous paper, the cited papers are missing from the references, and a whole series of elements are mentioned which never show up in the rest of the manuscript. In summary, I recommend that this study

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is potentially very interesting and fitting in Biogeosciences, but still needs a lot of work. As such I recommend to return the manuscript to the authors with major revisions.

Major comments The first proxy in the Abstract mentioned is Mg/Ca, which also starts the methods, but then there are no new results showing up in the rest of the paper. Meanwhile it seems that all relevant information on the Mg/Ca is actually in a previous paper (Steinhardt et al., 2014). We have omitted this section from the manuscript. Initially we added some new data from the F-0 chamber, but ultimately this did not add any new insight. Therefore, and also to avoid any unnecessary overlap, we now refer to the Steinhardt et al 2014 paper for the Mg/Ca data. At the end of the ms d13C comes in, almost as a kind of afterthought. I suggest to make the paper more clear in what it really wants to tell the reader, to make it something which can stand on its own without needing other papers. The Mg/Ca measurements were done by Laser Ablation. Accordingly, test profile Mg/Ca will be representative of the migration of the foram through the water column. In the previous paper it was mentioned that this variability was not considered. Why is this source of information left out? The average of the profiles is taken as indicative for temperature, so the different parts should be too then and thus will give you temperatures of the different depths of calcification. The test profile Mg/Ca data is influenced by many other factors as well. The formation of crust and cortex influences the Mg/c a profile for instance as well. We have for now omitted the Mg/Ca data, whereas detailed shell wall profiles are part of another manuscript.

Comments: Referee: Section 3.4: If parts are copied from previous papers then at least be precise and include the references into the new reference list. Several references (Reichart et al., Raitzsch et al., Jochum et al., Duenas-Bohorquez et al.) in the methods (3.4) are missing. Is it relevant for the paper that Na, Mn, Sr, Cd, Ba, and U have been measured? "695 values were obtained for 373 specimens". Please explain, are these averages values for test profiles or single shots on the tests? If new data were measured for this study as written before, then show profiles how the data were generated.

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Author's response: We apologize for this mistake. We have now omitted the entire LA-ICP-MS section, also in response to comments by the other referees. The methods section for the other elements is in fact a remnant of a previous version of the manuscript that somehow escaped the scrutiny of all authors. We have carefully re-checked the reference list and added missing references, when necessary.

Referee: Results, Mg/Ca: This is very confusing! Are new data being presented or not? Ranges and temperatures are being mentioned; and differences in subsequent chambers of dutertrei, but no figures are showing these data. Going back to the Steinhardt et al., 2014 paper it is possible to find these data. But that would suggest that the current manuscript cannot stand on its own, it needs the reader to have the other paper along with it.

Author's response: Again we apologize for this mistaken. Whereas we initially wanted to present new data on F-0, this provided no new insight. Therefore we have omitted the entire section on la-icp-ms and now refer to the Steinhardt et al., 2014 paper. For completeness we have added the Mg/Ca data to Table 2s, as this allows one-to-one comparison of the data. The table caption refers for the Mg/Ca data to the initial publication.

Minor comments Referee: Abstract: "i.g.": I assume you mean "i.e." with this? Author's response: This has been changed accordingly to "i.e." Referee: Page 4, line 7: Ortiz 5-22: Steinhardt et al., accepted? Author's response: Changed to Ortiz et al., 1996 and Steinhardt et al., 2014. Referee: 7-14: "as previously described"; it is not very extensive to include this, it will be helpful. Author's response:Text has been changed into: according to Barker et al., (2003), modified after Fallet et al., (2009).

Referee: 7-17: how are eddy or non-eddy conditions separated?

Author's response: Separation of eddy and non-eddy condition was described in detail in Steinhardt et al., 2014. We now include a citation to refer to the explicit to this description in Steinhardt et al., 2014.

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Referee: 7-23: the mooring is not present in fig.1.

Author's response: Figure 1 has been changed and includes now a detailed mooring array with the location of the sediment traps as well as a sea level anomaly snapshot showing the passing of an eddy during the deployment.

Referee: 7-26: how significant is a meterwise resolution?

Author's response: On the ten-meter scale resolution relevant for planktonic foraminiferal habitats, the one meter resolution seems adequate.

Referee: 8-15: *ruber* s.s. or *ruber* s.l.?

Author's response: We added a sentence to page 17262 line 17: "To minimize a potential bias associated with the lumping of different morphotypes (Steinke et al., 2005), we used only *G. ruber sensu stricto*, that was by far the most abundant (Fallet et al., 2010)."

Referee: 8-25-27: it is mentioned several times in the text that no size-related trends were present. Was this based on the few specimens mentioned here which were taken from a larger size fraction? In general, size-related effects in forams for isotopes and Mg/Ca are only found when including the more extreme size fractions, i.e. <250 or >400. Anything in-between does not show any trends.

Author's response: Point appreciated, still we included a paragraph about possible effects to emphasize that differences in our data set cannot be explained with size-related effects.

Referee: Section 3.4: see above. Line 5: "expanded", so extra profiles were lasered on the last chamber? These data should be shown.

Author's response: Based on the comments of the other referees as well as this comment, we decided to omit the additional Mg/Ca data. See discussion at several points above.

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Referee: 10-16: delete "and"; Author's response: The sentence was changed accordingly.

Referee: lines 16-18: "are in good agreement". Be specific, give numbers.

Author's response: We have now added a table (Tab. 2) into the method section showing the exact numbers.

Referee: Page 11: it is unclear which dataset was used for  $\delta^{18}\text{O}_{\text{sw}}$ , from the global dataset or from the measured samples? Is this a new relationship for  $\delta^{18}\text{O}_{\text{sw}}$  and salinity? If not, include a reference.

Author's response: This was mentioned in paragraph on page 17265 line 4-8: "We extracted  $\delta^{18}\text{O}_{\text{sw}}$  values from the South Indian Ocean for the upper 2000 m (4.5 - 120.2°E; 0 - 32.9°S, N=154) from the Global Seawater Oxygen-18 Database [<http://data.giss.nasa.gov/o18data/>]. We also mentioned that we additionally included some one new  $\delta^{18}\text{O}_{\text{sw}}$  measurements from the MC, from near to the sediment trap location (41.08°E; 16.74°S). This one point merely confirmed the regional relationship between  $\delta^{18}\text{O}_{\text{sw}}$  and salinity". We included now an additional supplementary table with the  $\delta^{18}\text{O}_{\text{sw}}$  data used here.

Referee: Why did you use the Kim and O'Neil equation and not the species-specific equations?

Author's response: In our opinion the Kim and O'Neill data set is the most general calibration allowing to compare inter specific differences which are automatically accounted for when using species specific calibrations. We have added this to the manuscript.

Referee: 12-4: add brackets to 2014; which temperature calibrations were used to calculate temperatures? Do these data include the data from the previous paper too or just the new data? Author's response: We have changed the sentence accordingly and now state that the temperature equation of Kim and O'Neil was applied. Both

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previously published Mg/ca and new  $\delta^{18}\text{O}$  data was utilized to calculate temperatures.

Referee: Intertest variability in *ruber* is highest. This is counter-intuitive if the species is the one which is migrating the least of all, sticking most of its life cycle close to the surface. How can this be explained?

Author's response: This is explained by the fact that the highest temperature variability is also observed at the sea surface, in contrast to the more stable deeper parts of the water column. This is in fact a very nice observation, in line with our model, which is now added to the discussion. Also differences in symbiont activity are probably highest within the euphotic zone.

Referee: All the numbers in the Results section make it very confusing to read. Please add tables for this to give a much better overview.

Author's response: We followed this and the other referee's suggestion and now included a table with the results.

Referee: 14-11: "multi-specimen"? and equation 4 should be 3 I guess.

Author's response: "Multi-specimen" is based on the fact that we here averaged Mg/Ca and  $\delta^{18}\text{O}$  data for all specimen of each species.

Discussion. 5.1: Referee: what is the message of the first paragraph? It is well-known that *G. ruber* is a shallow dwelling species. This can be shortened considerably.

Author's response: The main message of this section was the potential role of seasonality on skewing the average temperature recorded in the shells of *G. ruber* towards the warmer season.

Referee: 15-23: Loncaric is spelled incorrect on several occasions.

Author's response: We have corrected this mistake throughout the manuscript.

Referee: 16-3: remove brackets for 40-150. These ranges in reconstructed depths are

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the interesting thing in the paper instead of an average depth of 37 m. Apparently even under "stable" conditions you do already get such a large spread. Where does this come from?; "pooled specimen" in general this is not much more than 5 specimens, how representative are those measurements then for the population?

Author's response: We analysed the complete population present within the sediment trap for each interval, hence it is 100% representative. Still, we agree that the observed variability is considerable and our measurements do underline high intra-specimen variability. Moreover, the data explains some of the variability observed within a population.

Referee: 16-10: why not compare to your own *dutertrei* Mg/Ca?

Author's response: We agree with the referee and added now a comparison of the average Mg/Ca-based temperature ( $22.5 \pm 4^\circ\text{C}$ ) and the average  $\delta^{18}\text{OCC}$ -derived temperature ( $24.3 \pm 2^\circ\text{C}$ ), which are in good agreement.

Referee: 16-15/22: includes a series of typos.

Author's response: We have carefully re-checked this section for typos and corrected when present.

Referee: 16-23: Mohtadi et al., 2009 is missing from the references.

Author's response: This reference has been added to the reference list.

Referee: 17-6: this would fit it then with the Mg/Ca; how are the vital effects for the other species?

Author's response: The vital effect was only obvious for *G. scitula*. The other species are within the ranges previously suggested.

Beginning 5.2: Referee: any geochemical signal recorded in a foram test is an average of the range over which calcification took place. So all reconstructed calcification depths are apparent.

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Author's response: We agree with the referee and merely used the term "apparent" to stress this. Referee: 18, middle paragraph: this belongs in the results and/or a table; last paragraph is confusing, please clarify.

Author's response: Since we are here discussing "inferred temperature" we think this belongs in the discussion. The last part of the paragraph was rephrased highlighting that the  $\delta^{18}\text{O}$  was similar, but inferred calcification depths not.

Referee: 19-6: "trends with test size", see comment before.

Author's response: This has been changed based on an earlier comment.

Referee: Lines 6-20: what about the rest of the variability? And this would be the case for every species. The larger their depth range, the larger the variability would become.

Author's response: This might be counterintuitive to the reviewer, but the temperature variability becomes less with increasing depth. Still, we appreciate the comment, as based on this we now also realize that the foraminifera are apparently very stable in their calcification trajectory as this would otherwise have added considerably to the variability.

Referee: 19-26: which is which in this sentence?

Author's response: We do not understand to what sentence of the manuscript this comment is referring.

Referee: 20. first part: this uses the final chamber Mg/Ca or the overall Mg/Ca? These data should also go into a table. You can leave all these numbers out of the discussion then and just refer to the table.

Author's response: This data has been added to the table.

Referee: Model: how are the two constants determined?

Author's response: The two constants were determined first using the Mg/Ca-based

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temperature of the F-1 chamber, to delimit the depth at which 95% of the calcite production was completed and subsequently matching  $\delta^{18}\text{O}$  expected to the measured  $\delta^{18}\text{O}_{\text{occ}}$ . This is now clarified in the revised manuscript.

Referee: 23-14: "extended version". This is mentioned but not shown. The impact of secondary calcification is well-known and can take up the majority of the shell mass, not only in *scitula* but also in *dutertrei* and *obliquiloculata*.

Author's response: We fully agree with the reviewer that the addition of secondary calcite potentially plays a major role in the overall carbonate addition. The model used here is, however, not able to separate the curve into two different parts, each with his own fractionation. Whereas this would be very interesting, separate fractionation factors for both lamellar and crust calcite would be needed, which do not exist at the moment.

Referee: 24-9: remove the size trend part.

Author's response: Line 9 on page 24 is not mentioning size trends.

Referee: 25-8: Why are all expected values higher than the measured ones?

Author's response: This is discussed at page 17279 lines 28-30: there is a temperature dependent offset in  $\delta^{13}\text{C}$ .

Referee: 26-11: How does the  $\delta^{13}\text{C}$  indicate that Mg/Ca is a good indicator?

Author's response: The carbon isotopes are used as an independent check. The calculated  $\delta^{13}\text{C}$  overall matches the measured  $\delta^{13}\text{C}$ , with offsets that can be explained with what is known from literature. Since the Mg/Ca was used to drive the model, this fit indicates that Mg/Ca agrees well with calcification temperature of the individual chambers.

Figures: Referee: No new Mg/Ca data are shown

Author's response: This has been addressed in the previous points (see comments to

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previous referee).

Referee: it would be interesting to see how the data vary with temperature (and salinity) during the time the sediment trap was employed. Do the analysed data follow natural changes?

Author's response: This is exactly what the paper aims at: we contrasted temperatures from eddy versus non-eddy times. Previous studies (Fallet et al.) addressed seasonal trends as well.

Referee: Fig. 4b: why is this split up into different chambers? The exponential fit is not very convincing. The data may also be seen as constant values up to 20°C and a linear increase >20°C. Remove the 2 from the Mg/Ca axis that is not going to be a real value; this figure integrates all different species and different growth stages.

Author's response: The fact that this correlates at all (which is a statistic fact and not something to believe or not) is quite remarkable. The correlation coefficient also indicates that close to 60 percent of the observed variability is not due to temperature alone. Part of the variability is related to comparing single chamber and whole shell data. Teasing out these effects is exactly what this manuscript aims at. These observations have now been added to the manuscript in the Figure caption of Fig. 4. Fig. 4 caption: "Figure 4: Scatter plot of Mg/Ca versus  $\delta^{18}\text{O}_{\text{cc}}$  (left panel). Right panel: single chamber Mg/Ca exponential relationship with  $\delta^{18}\text{O}$ -derived Temperatures calculated using Kim & O'Neil (1997). Regression:  $f = a \cdot \exp(b \cdot x)$ , with  $a = -0.7$ ,  $b = 0.06$ ,  $r^2 = 0.47$  using F-1/2 Mg/Ca from *G. ruber*, F-0 for *N. dutertrei*, *P. obliquiloculata* and *G. scitula* (black circles). F-1 for *N. dutertrei*, *P. obliquiloculata* and *G. scitula* (red circles) and F-2 for *N. dutertrei*, *P. obliquiloculata* and *G. scitula* (blue circles). Mg/Ca data from Steinhardt et al. (2014). Note that the correlation coefficient also indicates that approximately 60% of the observed variability is not due to temperature alone."

Referee: Fig. 5: there seems to be more discrepancy between Mg/Ca and  $\delta^{18}\text{O}$  than between eddy vs non-eddy;

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Author's response: We could not agree more.

Referee: fig.6: remove typos from the caption; what are the non-grey boxes?

Author's response: We have made changes according to the referee's advice. The grey box indicates the zone of the close-up on the right (upper 200 m). This is explained in the figure caption: "Figure 6: Apparent calcification depths of species are generally shallower during non-eddy conditions. Apparent calcification depths for eddy (red) and non-eddy conditions (blue) calculated from single specimen  $\delta^{18}\text{O}_{\text{cc}}$  using in situ temperature and  $\delta^{18}\text{O}_{\text{w}}$ . Calcification depth was determined by matching the measured foraminiferal  $\delta^{18}\text{O}_{\text{cc}}$  with the  $\delta^{18}\text{O}_{\text{eq}}$ , using the equation of Kim and O'Neil (1997). We used  $\delta^{18}\text{O}_{\text{SW}}$  from the species calcification depth. Grey box indicates the zone of the close-up on the right (upper 200 m)."

Referee: Fig.7: there is no axis for the Mg/Ca values. The figure is way too small. Figure caption: Figure 7: Cumulative calcification model for eddy (red) and non-eddy (blue) conditions from left to right: temperature profiles as well as  $\delta^{18}\text{O}_{\text{eq}}$  equilibrium ( $\delta^{18}\text{O}_{\text{eq}}$ ) for the upper 1000 m and  $\delta^{18}\text{O}_{\text{cumulative}}$  ( $\delta^{18}\text{O}_{\text{model}}$ ) for the upper 500m (a). On the upper far right, mass development/growth pattern, below cumulative mass of the foraminifera (foram mass) is plotted for the upper 500 m. Bulk  $\delta^{18}\text{O}_{\text{foram}}$  (triangles) Mg/Ca derived single chamber calcification depth (crosses) are indicated in the relevant plots for *G. ruber* (b), *N. dutertrei* (c), *P. obliquiloculata* (c) and *G. scitula* (d)

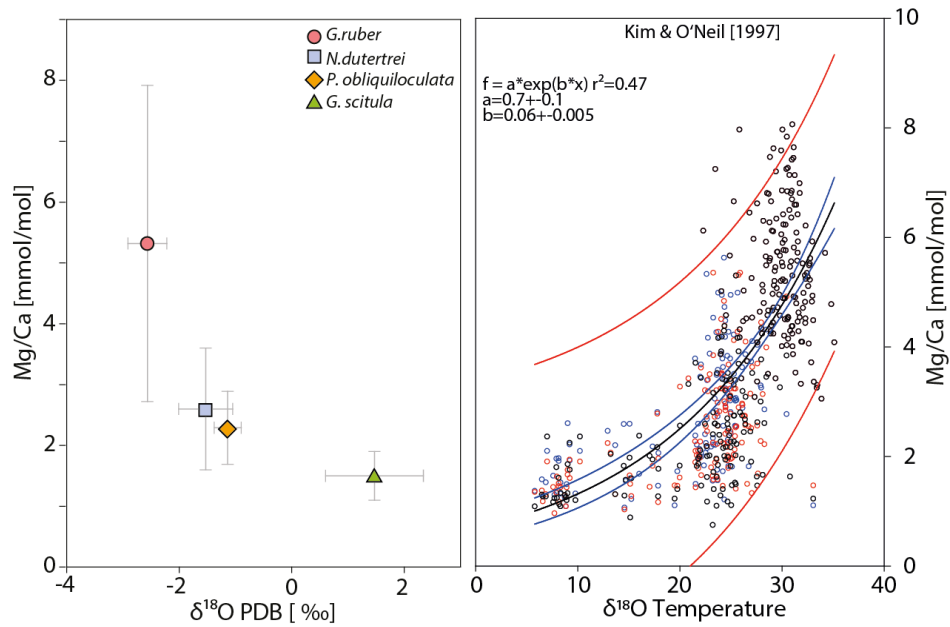
Author's response: There is no Mg/Ca axis, since Mg/Ca-based temperatures are plotted. We have changed figure size and layout.

Please also note the supplement to this comment:

<http://www.biogeosciences-discuss.net/11/C9084/2015/bgd-11-C9084-2015-supplement.zip>

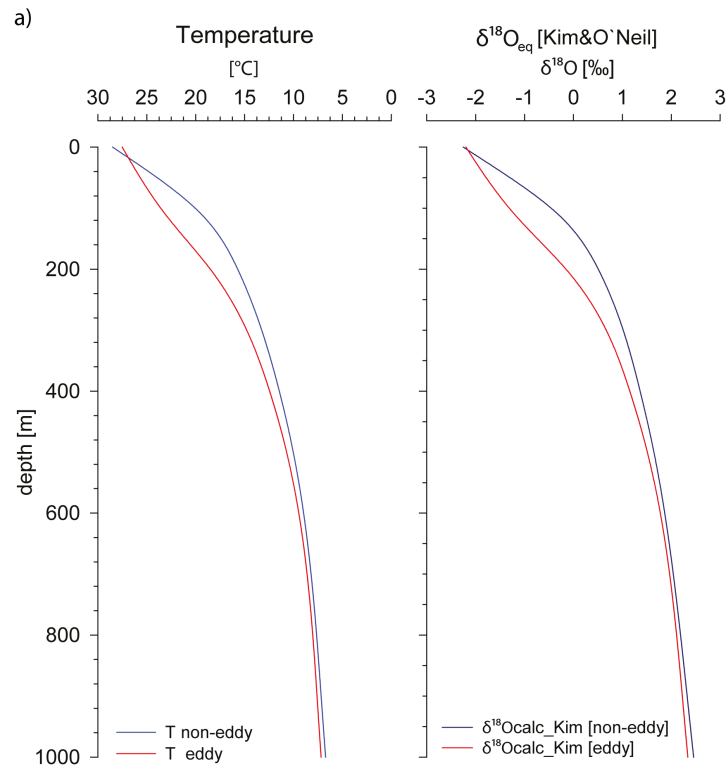
Interactive comment on Biogeosciences Discuss., 11, 17255, 2014.

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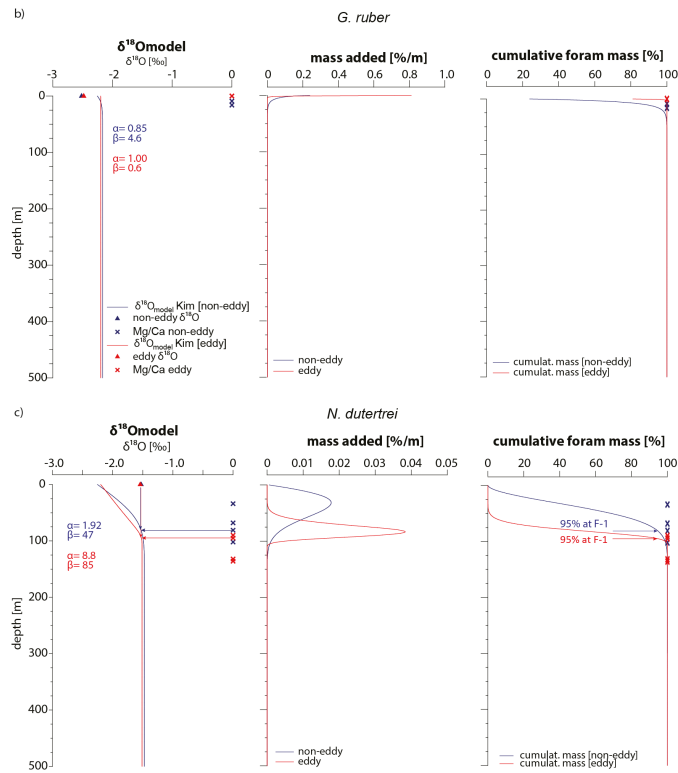
**Fig. 1.** Figure 4

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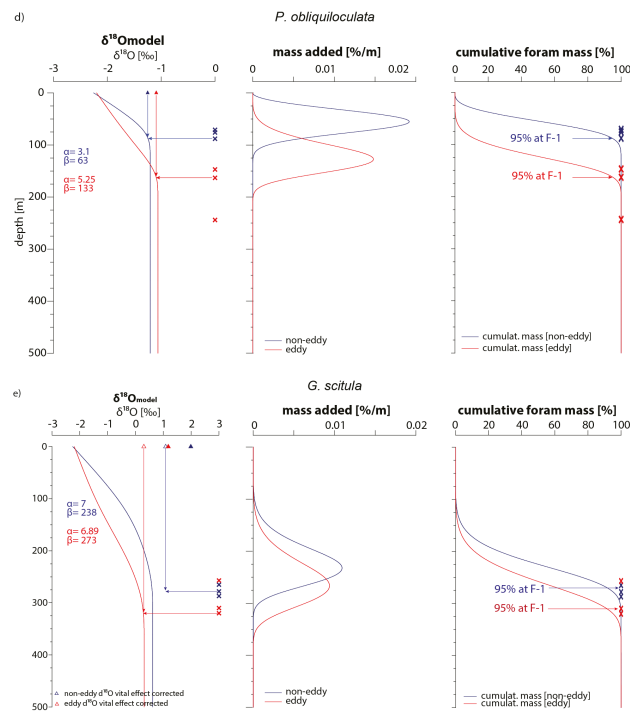
**Fig. 2.** Figure 7: Cumulative calcification model for eddy (red) and non-eddy (blue) conditions from left to right: temperature profiles as well as  $\delta^{18}\text{O}_{\text{equilibrium}}$  ( $\delta^{18}\text{O}_{\text{eq}}$ ) for the upper 1000 m and  $\delta^{18}\text{O}_{\text{cumul}}$

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**Fig. 3.** Figure 7: Cumulative calcification model for eddy (red) and non-eddy (blue) conditions from left to right: temperature profiles as well as  $\delta^{18}\text{O}_{\text{equilibrium}}$  ( $\delta^{18}\text{O}_{\text{eq}}$ ) for the upper 1000 m and  $\delta^{18}\text{O}_{\text{cummul}}$

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**Fig. 4.** Figure 7: Figure 7: Cumulative calcification model for eddy (red) and non-eddy (blue) conditions from left to right: temperature profiles as well as  $\delta^{18}\text{O}_{\text{equilibrium}}$  ( $\delta^{18}\text{O}_{\text{eq}}$ ) for the upper 1000 m and

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